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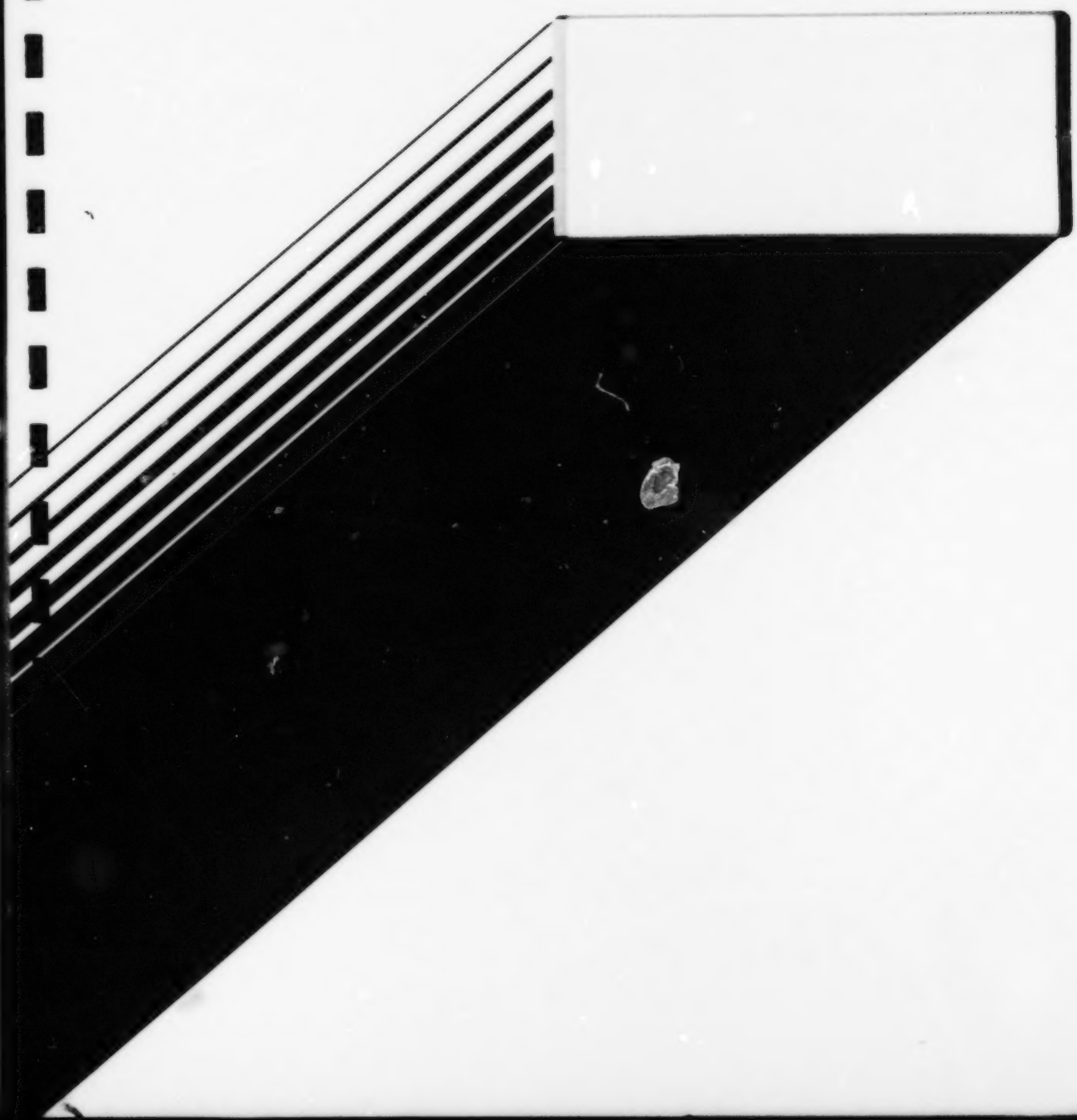

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THE CANADIAN APPROACH TO PROTECTION AGAINST POSTULATED PRIMARY HEAT TRANSPORT PIPING FAILURES

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PAPER

THE CANADIAN APPROACH TO PROTECTION AGAINST POSTULATED PRIMARY HEAT TRANSPORT PIPING FAILURES

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SUMMARY

In Canada, the Atomic Energy Control Act and Regulations stipulate in broad terms the requirements to be met by licensees. In addition, AECB staff have prepared licensing guides to amplify those requirements. For nuclear reactors, these include providing suitable protection against the consequences of failure of any pipe in the reactor cooling system. The suggested means of limiting the damage caused by whipping pipes or steam jets is by separation of equipment, installing barriers, or restraining piping. If, however, the designer can demonstrate that restraints are impractical or detrimental to safety, AECB staff may consider alternate arguments based on a demonstration that piping is likely to crack and then leak for a long time prior to rupture. This alternative approach would not be considered for ruptures having a high probability of defeating containment, damaging essential safety systems, or of disrupting flow to the core to the extent that fuel cooling could not be maintained.

RÉSUMÉ

Au Canada, la Loi sur le contrôle de l'énergie atomique et les règlements stipulent, dans les grandes lignes, les exigences demandées des titulaires de permis. Le personnel de la CCEA a préparé aussi des guides de réglementation pour développer ces exigences. Dans le cas des réacteurs, on demande une protection adéquate contre les conséquences d'un bris de n'importe quel tuyau du système caloporteur. Des dommages peuvent être causés par des jets de vapeur ou par le fouettement de tuyaux brisés, et les moyens de minimiser ces dommages sont de séparer les équipements, d'installer des barrières, ou de restreindre les tuyaux. Si un requérant peut démontrer que l'installation des contraintes n'est pas rentable, ou même à l'encontre de la sécurité, le personnel de la CCEA peut quand même accepter des arguments tendant à démontrer la probabilité, pour la tuyauterie en question, de fissurer et subir une fuite avant sa rupture. Cette méthode ne s'applique pas aux ruptures susceptibles d'endommager l'enceinte ou les systèmes essentiels à la sécurité, ou de mener à une diminution sensible du refroidissement du combustible du réacteur.

The Canadian Approach to Protection Against Postulated Primary Heat Transport Piping Failures

In Canada, the Atomic Energy Control Act and the Regulations made thereunder stipulate in very broad terms the powers of the Atomic Energy Control Board (AECB) and the requirements to be fulfilled by licensees. Since the Board has chosen to issue only skeletal regulations, the specific regulatory requirements are applied through the licensing process. For example, a licence condition requires the licensee to consider any type of failure at any location of the reactor main coolant system; draft regulatory guides C-7, C-8, C-9 (refs 1 to 3) describe the requirements for limiting the consequences of the postulated rupture to containment, shut-down systems, and emergency core cooling systems.

Application of the Act, Regulations, and guides in the licensing process is best illustrated by reference to the Darlington Nuclear Generating Station which is being designed and built by Ontario Hydro (the licensee).

The construction licence for Darlington includes the following condition:

Except as otherwise approved by the Board, all piping and headers which form part of the primary heat transport system shall be restrained to the extent necessary to ensure that their failure could not cause consequential damage which would render invalid the analyses in the Safety Report or other submissions to the Board.

In addition, Ontario Hydro was advised that the draft licensing guides, now in trial use, would be applicable to Darlington. The relevant sections from these guides are:

- from C-7; Requirements for Containment System

  > The containment system shall be designed such that, ... dynamic effects or jet forces caused by the event cannot result in impairment of the containment system to an extent that the relevant requirements in sections 2.2 (dose limits), 2.3 (structural integrity), and 2.4 (leakage) would not be met.

- from C-8; Requirements for Shutdown Systems

  > Each shutdown system shall be designed such that, ... dynamic effects or jet forces caused by the event cannot result in impairment of the shutdown system to an extent that relevant requirements in section 2.2 (performance) would not be met.

- and from C-9; Requirements for Emergency Core Cooling

  > The ECCS shall be designed such that, ... dynamic effects or jet forces caused by the event cannot result in impairment of the ECCS to an extent that relevant requirements in section 2.2 (cooling) would not be met.

During the evolution of the Darlington Station design, AECB staff discussed with the licensee the specific items in the guides. For example, the requirement that breaks be postulated at any location was perceived by the licensee as generating an infinite number of break locations. The AECB staff, however, considered that the consequences of rupture at certain 'critical' points could be shown to bound several others. Staff adopted this position because they did not believe that any alternate position based on the calculated stress and fatigue in piping could be supported by relevant pipe failure data. Jet forces, rates of flashing, impact dynamics, and damage scenarios were not specified but left to the designers to establish. Board specialists would then review the licensee's submissions for adequacy.

In order of desirability as the means of coping with the consequences of pipe failures, the licensee proposed: separation of equipment, installing barriers, or restraining piping. On Darlington, designers added the following specific features:

- some areas of containment, which could be subject to impact or jet loads, have been strengthened;
- boiler and piping layout has been separated into four quadrants to limit consequential damage to a local sector of the primary heat transport system;
- various structures, such as the pressurizer supports, have been strengthened to withstand the impact loads from pipe whip;
- concrete and steel barriers were introduced to protect shut-down systems from missiles and jets;
- some restraints notably on the headers and balance lines have been incorporated, to restrict reaction movements.

Despite these modifications, there remained 1100 break locations, on 250 mm lines and larger, which would require approximately 250 restraints costing several million dollars. Consideration of smaller lines would increase the number of restraints considerably.

The licensee asked Board staff to reconsider the licensing requirements for Darlington. The basis of the request was:

- the probability of piping failure is very low;
- restraints may increase that probability;
- restraints are difficult and costly to install;
- some restraints would impede or prohibit inspection;
- the piping will always leak for a considerable time before rupturing.

A review of the licensee's case led AECB staff to conclude that the licensee had not demonstrated that piping failures, including rupture, are sufficiently improbable that their consequences need not be considered. However, the staff were prepared to consider proposals to omit restraints in certain circumstances. Some of the considerations which led to this position were:

- a continuing awareness that catastrophic failure of nuclear standard piping is an improbable event. The U.S. Nuclear Regulatory Commission claims that a best-estimate probability of a double-ended guillotine break in a Pressurized Water Reactor (PWR) is 10^{-12} events per plant year. The failure rate for CANDU will be of a similar order of magnitude.

- the good performance of nuclear-grade piping worldwide. This despite there being corrosion- and welding-related problems in a large proportion of the world's reactors. None of these problems is evident in CANDU primary heat transport piping, mainly because the primary heat transport water chemistry is dedicated to controlling corrosion, whereas PWRs and BWRs also use the water chemistry for reactivity control.

- elimination of pipe-whip restraints would improve access to pipe welds for in-service inspection and thereby reduce occupational radiation exposure.

- the moderator and primary heat transport fluid are heavy water. Because this is very expensive, there is close control on and monitoring of leakage. Typically, station procedures require that leak rates above 50 kg/h (0.2 USGPM) be repaired within 24 hours or the plant shut down. This leak rate is an order of magnitude smaller than that recommended as an action level for PWRs and BWRs in the U.S.A.

- all the primary heat transport piping, feeders, headers, and pressure vessels are ferritic, typically 516 Gr70 and SA106 Gr. B. The in-service experience with these steels has been good; there have been no signs of in-service degradation, no problems associated with welding and, because they are ductile, they are tolerant of spurious loading.

It was not the intention of AECB staff that acceptance of a case to omit constraints be construed as acceptance that pipe breaks cannot occur and hence that containment or other safety systems need not be designed to withstand any of the consequences of pipe rupture. Consequently, the staff proposed that the consequences of pipe rupture at all locations in the main coolant loop should still be analyzed by the licensee.

It was also proposed that the plant design should be modified if necessary so that the consequences of failure are acceptable. The suggested means of achieving this continues to be, in order of desirability, separation of equipment, providing barriers, or restraining piping. If the licensee can show that these are impractical, an alternative safety analysis, to demonstrate that there is a long time between leaking and rupture (Leak-Before-Break), may be considered by AECB staff for certain break locations.

The degree to which restraints are considered impractical will be judged against the relative importance and likelihood of occurrence of the consequential damage. AECB staff is unlikely to accept alternative safety analysis for ruptures which have a high probability of breaching containment, or of damaging essential safety systems (Shutdown Systems one and two, and the Emergency Core Cooling System), or of disrupting flow to the core to the extent that the licensee cannot demonstrate to the AECB staff's satisfaction that fuel cooling can be maintained.

Staff of the AECB also proposed that alternative safety analysis should include:

- a description of the consequences of the break(s) for which protection is not provided;
- reasons why protection is impractical;
- test data to show that material ductility and fracture toughness are adequate to ensure leak-before-break behaviour. This should also include consideration of weld material;
- an In-Service-Inspection program for the section of piping for which restraints are not provided. This would replace Canadian Standard 285.4, which defines the areas of inspection using stress and fatigue criteria, with the volumetric requirements of ASME XI for class 1 piping plus wall-thickness measurements of the bends.
- a fracture analysis demonstrating that leak-before-break will occur for design transients causing the greatest stress at the point, and in the direction, of interest. The design transient should be selected from ASME level A (design) to level D (emergency) events. The fracture analysis should include consideration of residual stress, material degradation, 90° circumferential through-wall cracks, and axial cracks as long as four times the wall-thickness.
- a leak detection system capable of responding to the leak rate through a crack, as long as twice the wall-thickness, under ASME level A (design) loading. The crack should be postulated at the least detectable position on the piping for which restraints are not to be provided.

These proposals are applicable only to ferritic steels used in class 1 piping, and to class 1 welds which have been stress relieved. Piping or welds which include defects dispositioned prior to service are also excluded.

In conclusion Board staff have reviewed the practice worldwide for the protection of reactor equipment against the consequences of breaks in large diameter pipes. This led to an approach, for the licensing of Darlington, which while recognizing that large diameter pipe failures are infrequent, and are likely to leak-before-break, would maintain the

requirements for the protection of essential safety systems. In practice this permits the number of piping restraints to be reduced while maintaining the principle of defence-in-depth.

References

1. AECB Consultative Document C-7: Proposed Regulatory Guide - Requirements for Containment Systems for CANDU Nuclear Power Plants May 1982

2. AECB Consultative Document C-8/Rev. 1: Proposed Regulatory Guide - Requirements for Shutdown Systems for CANDU Nuclear Power Plants May 1982

3. AECB Consultative Document C-9/Rev. 1: Proposed Regulatory Guide - Requirements for Emergency Core Cooling Systems for CANDU Nuclear Power Plants May 1982